FINAL REPORT

19980201

DETERMINATION OF RISK FACTORS FOR PERINATAL MORTALITY IN FARMED ELK

March 2003
Funded by the Agri-Food Innovation Fund

Prepared by: University of Saskatchewan

AGRI-FOOD INNOVATION FUND

Canada

Saskatchewan

103-04312/

A retrospective study of neonatal mortality in farmed elk

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This work was conducted in partial fulfillment of the requirements for a Master of Veterinary Science Degree at the University of Saskatchewan by Dr. Pople.

Funding of this study was provided by the governments of Canada and Saskatchewan through the Canada-Saskatchewan Agri-Food Innovation Agreement. Dr. Pople was supported by a Western College of Veterinary n Interprovincial Graduate Student Fellowship.

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Abstract

Despite the increasing importance of the Canadian elk industry, the veterinary literature on elk diseases is sparse, in particular for the neonatal period. This study summarizes necropsy findings in 111 elk calves, up to 30 days of age, submitted to the Western College of Veterinary Medicine over a 9-year period (1990 to 1998). Causes of mortality fit into 3 categories: infectious disease, noninfectious disease and undetermined. Organisms causing disease included *Escherichia coli, Listeria monocytogenes,* and *Cryptosporidium* sp. Starvation, including dehydration, was also a significant cause of mortality. Necropsy records are a useful source of information, but their scope is limited. There is a need for research that determines the prevalence of neonatal elk diseases and identifies risk factors for morbidity and mortality.

The Canadian elk industry has expanded considerably in recent years. The estimated number of farmed elk has risen from just over 3,000 in 1991 (Saskatchewan Agriculture and Food, unpublished data) to more than 57,500 in 1999 (1). Most of these animals are found in Alberta (25,629) and Saskatchewan (24,573), representing approximately 44.5% and 42.7%, respectively, of the Canadian total (1). Most of the existing literature on farmed cervids is based on captive red deer in New Zealand and the British Isles. Literature on diseases of captive elk is less available (2), and there is minimal specific information on causes of mortality among farmed elk calves during the 1st month of life. Neonatal diseases similar to those affecting cattle, such as *Escherichia coli* diarrhea, coronaviral enteritis, and cryptosporidiosis, have been reported in elk calves (2,3). However, there is evidence that management and maternal factors may be more important contributors to neonatal mortality in captive management systems; for example, deaths due to starvation and trauma are common (3). There are also reports attributing a large proportion of calf loss to dystocia (4,5). The purpose of this study was to summarize causes of neonatal mortality in elk farmed in Saskatchewan by reviewing cases submitted to the diagnostic laboratory at the Western College of Veterinary Medicine (WCVM).

Materials and methods

Necropsy records for elk calves submitted to the WCVM during 1990 to 1998, inclusive, were reviewed. Submissions of both whole carcasses and portions of carcasses collected from field necropsies were included. Portions consisted of formalin-fixed tissues, fresh (unfixed) tissues, or both. Only calves that died during the first 30 days of life were selected for further study. Data collected included the age and sex of the calf, the postmortem diagnosis, and any identified infectious organisms that were associated with mortality. Reports by the submitter of dystocia (difficult or assisted birth) or of orphaning (permanent separation from the dam for any reason) were also recorded. With respect to the submission of portions of tissues, whether the samples were fixed, fresh, or both was noted. The association between making a specific diagnosis and the submission of whole carcasses rather than portions was tested by using Fisher's exact test (Prism version 3.00, GraphPad Software, San Diego, California). The odds ratio, 95% confidence interval (CI), and *P*-value were also calculated.

Results

During the 9-year study period, submissions from 111 elk calves were received, 76 whole carcasses and 35 portions. Fourteen (12.6%) calves either were dead at birth or died during the first day of life. Fifty (45.0%) died between 2 and 10 days of age; 27 (24.3%) calves between 11 and 20 days of age; and 20(18.0%) between 21 and 30 days of age, all days inclusive. Forty-five (40.5%) calves were male, 33 (29.7%) female; the sex of the remaining 33 (29.7%) calves was not specified.

The postmortem diagnoses could be grouped into 3 categories: infectious disease, noninfectious disease and undetermined (Table 1). Most cases of infectious disease involved calves with multisystemic inflammation, the isolation of the same bacteria from multiple organs, or both, consistent with bacteremia or septicemia. Etiologic agents are summarized in Table 2. Most of the calves diagnosed with noninfectious disease died of starvation (emaciation) or trauma. Cases for which necropsy did not reveal the cause of death or illness were placed in the category "undetermined".

Thirteen (11.7%) calves had been assisted at birth, and 20 (18.0%) calves were reported to have been orphaned prior to death. Six calves that were assisted at birth were later orphaned and died of an infectious disease. Six other orphaned calves died of an infectious disease, while an additional 6 died of a noninfectious disease.

A diagnosis was made on 55 of the 76 (72.4%) whole carcasses, but on just 10 of the 35 (28.8%) submissions involving portions. The odds ratio for making a diagnosis on a submission of a whole carcass versus only a portion was 6.5 (CI, 2.7–15.9; $P<0.0001$).

With regard to the submission of portions, the selection of tissues and the request for various diagnostic tests, such as histologic examination, bacterial culture, and virus identification, was at the discretion of the submitting veterinarian and may have been modified at the judgement of the pathologist managing the case. All 35 cases involving only portions included the histologic examination of tissues, 30 cases included attempts at isolating bacteria, and 19 cases included attempts at identifying one or more viruses by means of isolation, fluorescent antibody testing, immunohistochemistry, or a combination of these techniques. The combinations of tissues received, the state of the tissues (fixed or fresh), and the tests performed were so numerous that a summary was neither practical nor useful. Attempts to associate the examination of specific tissues, tests performed, and the ability to arrive at a specific diagnosis was not feasible.

Discussion

The important causes of mortality found in this study reflect previous reports on diseases of neonatal elk and red deer. Among cases for which a diagnosis was made, infectious disease accounted for most of the deaths, but there were also several deaths related to starvation, including dehydration, or trauma.

The isolation of *Escherichia coli*, in pure or mixed culture, from the majority of calves with multisystemic infections is consistent with a survey of elk necropsy records published in 1992 (3). In this study, *E. coli* was not found to be a major cause of enteritis. It is believed that elk calves acquire enteric or multisystemic *E. coli* infections under the same circumstances as do domestic cattle, that is, lack of passive immunity or unsanitary environmental conditions (2).

The only other bacterium isolated from more than 1 case was *Listeria monocytogenes*. This organism has been reported as a cause of abortion and neonatal septicemia in red deer in the United Kingdom (6) and has been isolated from free-ranging elk in California (7). Haigh and Hudson (2) may have reported some of the same animals reviewed in this study in their review of listeriosis.

Cryptosporidium sp. was the organism most frequently isolated in elk calves with enteritis. Four of the 7 cases were part of an outbreak on a single farm. In New Zealand, several outbreaks of enteritis in red deer calves have been attributed to *Cryptosporidium*. Although the incidence in the New Zealand population is low, individual herds have experienced calf mortality of 30% to 40% (8,9). Mortality of 70% and 100% occurred in 2 groups of red deer calves that were kept indoors and hand-reared (10).

Rotavirus and coronavirus are believed to be important causes of neonatal enteritis in captive elk and red deer (2) and both viruses have been reported to cause death in free-ranging elk calves in Wyoming (11). In contrast to earlier work that identified coronavirus as the most common cause of neonatal enteritis (3), no cases with coronavirus were found in this study.

Ten percent of calves in this study were found to be emaciated or dehydrated and without any evidence of infectious disease. Calf abandonment may account for many of these cases, as it appears to be a common problem in captive elk. Cows calving for the first time are believed to be more likely to reject their calves (3). Dystocia and human interference at the time of parturition are also predisposing factors for calf rejection (12,13). Elk calves with birth weights below 11.4 kg have less than a 50% chance of surviving to 4 weeks of age (14), but the reasons for this are not clear. Elk and red deer cows in poor body condition have lighter calves and presumably deficient milk production (14,15). Postnatal malnutrition may be the main contributor to the decreased survival of low birth weight calves, but there may be other factors that make these calves nonviable. Calves that are twins or triplets tend to be small and the dam may not produce enough milk to sustain more than 1 calf (4,16).

Trauma is an important cause of mortality in elk of all ages (3). Calves that are rejected may be attacked by the mother when they persist in attempting to nurse. In situations of high density or other stressors, hinds may victimize calves belonging to other females (2,12). Only a few of the calves in this study died because of trauma, but it is reasonable to assume that animals with obvious wounds or fractures are less likely to have been submitted for necropsy.

Selection bias is a serious limitation on the usefulness of retrospective studies that are based on necropsy records (17). There are numerous factors that determine whether or not a dead

134 animal will be submitted for necropsy. For example, producers may feel that they know the cause
135 of death and a necropsy is therefore not worth the cost. Further, they may be more concerned
136 about disease outbreaks than about sporadic deaths. Also, the degree of veterinary involvement
137 on elk farms is highly variable, as is the degree to which individual veterinarians use diagnostic
138 services. Finally, the proximity of a farm to a diagnostic laboratory may influence the rate at
139 which calves are examined after death and the nature of the submission (the whole carcass of
140 portions of tissues). Overall, the percentage of dead animals that are examined by pathologists is
141 probably small and these animals are unlikely to be a representative sample.

142 The large proportion of nondiagnostic submissions (41.4%) also impedes the use of these
143 necropsy records as a sample of elk calf mortality. In the first few weeks of life, elk calves spend
144 a large amount of time in hiding (18). They can be very difficult to observe, even with minimal
145 cover. Consequently, producers may not notice signs of illness and dead calves may not be found
146 before they are scavenged or become autolyzed. Submitting portions of tissues is often more
147 practical, but this study found that pathologists are more likely to diagnose the cause of death
148 when given a whole carcass. Even then, there are limitations. Lesions are often not apparent
149 when death results from periparturient hypoxia. Although it may be unavoidable, the low
150 diagnostic rate raises the possibility that certain diseases are underrepresented in this study.

151 Because of the aforementioned factors, it is probable that these records do not reflect the
152 true range and incidence of fatal diseases that occur in the local captive elk population. There is a
153 need for prospective epidemiologic studies in which complete information on the management
154 and environment of elk farms is collected. Data must be obtained on all calves that die in order to
155 construct a realistic mortality profile. Risk factors for mortality can only be determined by

156 comparing the dead calves to surviving calves and by comparing farms with different mortality

157 rates.

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Table 1. Cause of death diagnosed in 111 neonatal elk submitted for examination between 1990 and 1998, inclusive

General cause of death	Specific cause of death	Number of cases	% of total
Infectious disease (n = 41)		41	36.9
	multisystemic	26	23.4
	infection	13	11.7
	enteric infection	2[a]	1.8
	other		
Noninfectious disease (n = 24)		24	21.6
	starvation	11	9.9
	trauma	7	6.3
	other	6	5.4
Undetermined (n = 46)		46	41.4
Total		111	99.9[b]

[a]1 calf died of pneumonia and 1 calf died with omphalitis and hepatic necrosis of undetermined cause

[b]Totals do not equal 100% due to rounding

Table 2. Organisms isolated from neonatal elk diagnosed with an infectious disease at necropsy[a]

Infectious disease	Etiology	Number of cases
Multisystemic infection (n = 23)		
	Mixed bacteria	10[b]
	Escherichia coli	9
	Listeria	2
	monocytogenes	1
	Citrobacter freundii	1
	Aspergillus sp.	
Enteritis (n = 11)		
	Cryptosporidium sp.	7
	Rotavirus	2
	Escherichia coli	1
	Clostridium	1
	perfringens	
Total		34[a]

[a]In 5 additional cases, infectious disease was diagnosed on the basis of inflammatory lesions, but no organisms were isolated

[b]Of these 10 cases, 8 included *E. coli*, and 2 included *L. monocytogenes* as one of the mixed bacteria

A study of neonatal mortality in farmed elk

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This work was supported by the governments of Canada and Saskatchewan through the Canada-Saskatchewan Agri-Food Innovation Agreement, the Western College of Veterinary Medicine Specialized Livestock Research and Development Program, and Prairie Diagnostic Services.

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Abstract

A 2-year study involving 1,054 farmed elk calves born to 1,028 hinds was conducted to investigate neonatal mortality. The neonatal mortality rate was almost 6%. Most stillbirths were related to dystocia. Bacterial sepsis accounted for most deaths after birth. Failure to nurse contributed to many of these deaths and those due to hypoglycemia and dehydration. Deaths related to developmental anomalies and accidents were uncommon. Calves seen to be ill, having an assisted delivery, orphaned, or delivered early in the calving season were more likely to die. While neonatal mortality was not an unreasonable source of reproductive inefficiency, relatively small measures could likely lower rates. Hinds should not calve before mid-May, carry twins to term, or become overweight and unfit. Young and inexperienced hinds may also be at higher risk. Hinds at higher risk should be monitored more closely at parturition and assistance, if needed, provided as quickly as possible. Artificial rearing should be considered for calves assisted at delivery, orphaned, over-mothered, or otherwise ill. Ill calves should be treated by veterinarians.

The farmed elk *(Cervus elaphus)* industry is recognized as a distinct and viable agricultural enterprise in Canada (1). As of December 31, 2001, an estimated 1,000 elk farms located in 10 provinces and territories were raising about 85,000 animals. Most of the farms (857) and animals (74,000 or 87%) were located in Alberta and Saskatchewan (Saskatchewan Agriculture, Food and Rural Revitalization, unpublished data). In the past, elk farm income has been associated principally with the production of breeding stock and velvet antler, and to a lesser extent with the sale of trophy bulls and venison. It is believed that, once farmed elk populations have reached a level where demand for breeding stock is met, a shift to the production and sale of venison will occur (1).

Although market pressures will determine the type and extent of production associated with elk farming, income and profitability have been, and will be, influenced by reproductive efficiency. An important cause of reproductive inefficiency in other livestock industries is neonatal mortality (2). However, few descriptions or formal studies of neonatal mortality in farmed elk have been published in the scientific literature (3-6). These publications have either been limited by reliance on the producer to report the cause of death, or suffered from selection bias as the study was based on only calves submitted to a diagnostic veterinary laboratory for postmortem examination. To the best of our knowledge, a study of farmed elk calf mortality, including information on all calves dying during the neonatal period, postmortem investigation of the cause of death by veterinary pathologists, and collection of information on the surviving calves for comparison, has not been done.

The broad objective of this study was to learn more about neonatal morality in farmed elk. The specific objectives were as follows: (i) collect and summarize data from selected

Saskatchewan elk farms regarding calf production, neonatal mortality, and factors potentially important to calf survival and mortality (ii) examine all neonatal elk that died on selected Saskatchewan elk farms to determine the cause of death, and (iii) determine the role of peripartum events, hind characteristics, and management practices as risk factors for neonatal mortality.

Materials and Methods

Multiple elk farms within 200 km of the Western College of Veterinary Medicine (WCVM) were approached about participating in this study. In 1999, 10 farms agreed to participate and in 2001, 15 farms participated. Seven of these farms participated in both 1999 and 2001. Prior to the calving season, questionnaires were administered to obtain information about individual pregnant hinds, management of pregnant hinds, and the farm environment. During the calving season, producers completed a second questionnaire and record of events concerning the delivery and management of each calf.

All producers were instructed to inform the investigators of any stillborn calves, or any calves dying during the first 30 days postpartum. Carcasses were collected from the farm as quicky as possible and examined at Prairie Diagnostic Services at the WCVM by one or more of the authors. Carcasses were weighed and measured, and a thorough postmortem examination performed following a standard protocol. Any organs or tissues with lesions identified grossly, as well as a standard set of 18 organs and tissues, were collected, fixed in 10% buffered formalin, processed and stained routinely, and examined microscopically for abnormalities. Portions of at least two blood-filtering organs (e.g., liver, kidney, spleen) and any other organ or tissue thought to contain a lesion were cultured for bacteria. Any calf that had lived long enough to completely pass its meconium had portions of jejunum and spiral colon examined for rotavirus and coronavirus using a fluorescent antibody test, portions of small and large intestines cultured for bacteria, and feces from the rectum or colon examined microscopically for evidence of protozoa and other parasites.

Within the farmed elk industry, and for this study, the term 'hind' referred to any female of reproductive age, regardless of the number of calves she had produced (7). The neonatal period was defined as the first 30 days following delivery of a calf (2). Neonatal mortality included fully developed calves that were delivered dead, i.e., stillborn, and calves delivered alive and dying on or before 30 days of age. Early neonatal mortality included stillbirths and calves dying on or before 7 days of age. Dystocia was defined as any parturition that, in the opinion of the producer, was thought to be abnormally prolonged or difficult, or any labor that was assisted. Second stage labor in hinds typically lasts 2 to 3 hours (5,7). Any calf that was born alive and became permanently separated from its dam, for any reason, was considered an orphaned calf. Cross-mothering referred to a calf spontaneously nursing a hind or hinds other than its own dam. Over-mothering referred to the abnormal behavior of one or more hinds to excessively lick the perineal region of a calf resulting in lesions such as abrasion, ulceration, infection, and inflammation (7). The isolation of the same pathogenic bacteria from multiple organs, inflammation of multiple organs, or both, were criteria for a diagnosis of bacterial sepsis (6).

Data were managed on a personal computer using commercially available software (GraphPad Prism version 3.00, GraphPad Software, San Diego, California, and SPSS version 11.0.1, SPSS, Chicago, Illinois). Descriptive statistics, statistical tests (Fisher's exact test, chi-square test, *t*-test), and odds ratios (OR) (including confidence intervals (CI)) were determined with the aid of a calculator, and with commercially available software (Prism, version 3.00, and SPSS, version 11.0.1) on a personal computer. The Mantel-Hansel method was used to identify interaction.

Results

Neonatal Mortality

This study included 1,054 calves born to 1,028 hinds, with 26 hinds (2.5%) producing twins. The sex of 897 calves was recorded, and there were 475 males and 426 females, including 25 pairs of twins, i.e., 50 calves. Of the 25 pairs of twins, 9 were both males, 6 were both females, and in 10 pairs there was 1 male and 1 female.

Overall, 62 of the 1,054 calves (5.9%) either were stillborn or died within 30 days of birth. The neonatal mortality rate was 2.3% higher in 1999 (36 of 486 calves, or 7.4%) than 2001 (26 of 568 calves, or 4.6%). These 62 mortalities included 5 pairs of twins, i.e., 10 calves. Of the 62 dead calves; 20 (32.3%) were stillborn; 26 (41.9%) were born alive but died during their first 7 days; 7 (11.3%) were born alive and died between 8 and 30 days of age; and 9 (14.5%) calves were born alive, but the age at death was not known, other than it occurred before 30 days (Table 1). These 9 calves were not examined postmortem. Abridged descriptions of the 53 (85.5%) stillborn and dead calves that were examined postmortem appear in Tables 2 and 3, respectively.

The delivery of 15 of the 20 stillborn calves (75.0%) was associated with dystocia. Eight of these 15 stillborns (53.3%) were twin calves, and all 8 were delivered in 1999 (Table 2).

Of the 26 calves that were born alive and known to have died or been euthanized during the first 7 days, 15 (57.7%) had evidence of bacterial sepsis, with *E. coli* involved in 10 of the 15 cases (66.7%). Eight of the 15 septic calves (53.3%) had failed to ingest colostrum. An additional 3 calves, with no evidence of bacterial sepsis, had not nursed. One of these 3 calves was dehydrated, and a second was suspected to have been hypoglycemic prior to death as it seizured while being treated (see (8)). No evidence of meningitis or other lesions of the brain were found

during the postmortem examination. Two of the calves that failed to nurse had experienced dystocia and two others had been orphaned.

Four calves that were born alive had a history of a dystocia, and died within 48 hours. Problems related to dystocia were believed to have directly contributed to death. Two calves, 1 in 1999 and 1 in 2001, were euthanized during their first week of life because of developmental anomalies that were incompatible with life. Two other calves, 1 in each year of the study, died as a result of accidents, specifically drowning and being crushed by a truck.

Seven calves were born alive and were known to have died between 8 and 30 days. Five of these deaths (71.4%) were the result of bacterial sepsis, with *E. coli* involved in 3. One calf was euthanized at 22 days of age, because of perineal injuries associated with over-mothering.

Analysis for Risk Factors for Neonatal Mortality

Table 4 summarizes the association between categorical independent variables unconditionally associated with neonatal mortality, early neonatal mortality, or both, for the entire study, i.e., 1999 and 2001 combined. Tables 5 and 6 provide similar information for only 1999 and only 2001, respectively.

Peripartum Events

Calves that were seen to be ill by a producer (calf illness), had an assisted delivery, or became orphaned had much greater and statistically significant odds of dying during the neonatal period than calves without these risks. These associations were similar for early neonatal mortality, and in each year of the study.

150 It is important to note that calves which had an assisted delivery also had 35.10 times
151 greater odds (CI=12.30-100.20, $P<0.0001$) of becoming orphaned than calves which did not have
152 an assisted delivery. A stratified analysis revealed that among those calves that had an assisted
153 delivery, becoming separated from their dam was not a risk factor for neonatal mortality
154 (OR=0.60, CI=0.12-3.01, $P=0.7$). Considering only those calves that did not have an assisted
155 delivery, becoming permanently separated from their dam was strongly associated with neonatal
156 mortality (OR=47.93, CI=10.99-05, $P<0.0001$).

157 Cross-mothering was found to be associated with neonatal and early neonatal mortality in
158 this study. However, only 7 calves in 1999 and 8 calves in 2001 were reported to be cross-
159 mothered and, in 2001, none of the calves died during the neonatal period.

160 Overall, the odds of a pair of twin calves dying during the neonatal period was 4.35 times
161 greater than that for singleton calves, and 6.39 times greater during the early neonatal period.
162 These associations were stronger in 1999 than in 2001. However, a high proportion of twin calf-
163 pairs (6 of 26) had an assisted delivery. Therefore, a stratified analysis was performed and
164 revealed that the odds of a pair of twin calves being stillborn or dying during the first few days of
165 life was 38.00 times greater (CI=2.73-528.30, $P=0.005$) if delivery was assisted rather than
166 unassisted. Considering only singleton calves (n=1002), the odds of being stillborn or dying
167 during the early neonatal period was still 12.26 times greater (CI=5.02-29.93, $P<0.0001$) if the
168 delivery was assisted. Since no additional twin calves died after 7 days, the odds of a pair of twin
169 calves dying during the entire neonatal period did not change. However, an additional 16
170 singleton calves died after the early neonatal period and 5 of these had received assistance during
171 parturition. Therefore, the odds of a singleton calf being stillborn or dying after receiving

assistance during parturition, for the entire neonatal period, was 18.26 times greater (CI=8.30-40.32, $P<0.0001$) than calves not requiring assistance. Most of the neonatal mortality associated with twin calves was related to dystocia. None of the 16 calves that became separated from their dam were twins.

An attempt was made to determine if close observation of pregnant hinds late in gestation was associated with, i.e., prevented, neonatal mortality. To do this, we asked producers whether they had observed individual hinds while they calved. One-hundred-forty-seven calvings were observed and 601 were not, and a strong association (OR=4.44, P<0.0001) was found between an observed calving and neonatal mortality. However, since all assisted calvings were observed, and assisted calving was strongly associated with neonatal mortality, the real association between observation and neonatal mortality could not be determined.

Efforts were also made to learn if live calves that were seen to nurse during the first 24 hours after birth were more likely to survive past the neonatal period. Producers reported their observations for 761 calves. While there was a trend for calves seen to nurse to have greater odds of surviving the neonatal period (OR=1.75, CI=0.90-3.41), this association was not considered significant ($P=0.1$).

The date of birth was recorded for 901 calves. Eight-hundred-thirty-nine of those calves lived past 30 days, and 62 either were stillborn or died before 30 days. All surviving calves were born after May 11. In each year of the study, more than 50% of surviving calves had been delivered by the end of the first week in June and, overall, 78.3% of surviving calves were born during the 4-week period from May 18 to June 14 (73.1% in 1999 and 83.8% in 2001) (Figure 1).

193 During the 2 calving seasons on which this study was based, there was an impression that
194 a large proportion of calves contributing to neonatal mortality were delivered early in the calving
195 season. For example, the only calf delivered before May 11, was stillborn on May 9, 2001 (see
196 Table 2), and 50% of stillborns and calves dying before 30 days were delivered by the end of
197 May (see Figure 1). Further, overall neonatal mortality was higher (P=0.08), in May (9.3%) than
198 June (5.2%) or July (7.1%), although this was more the case in 2001 (11.8%, 3.0%, 5.0%) than
199 1999.
200 During this study, 19 of the 25 farms experienced at least 1 neonatal mortality. On 15 of
201 these farms, many of the calves that were stillborn or died were among the first few calves
202 delivered on that farm that year. In 10 instances, the first hind on the farm to go into labor
203 delivered a stillborn calf (or pair of stillborn calves) or a calf (or pair of calves) that died within 3
204 days. One additional hind delivered a calf on May 13 that was described as small, weak, and
205 lethargic. The calf was treated multiple times before dying at 25 days of age (see Tables 2 and 3).
206 All farms, during both years of the study, attempted to examine and handle their calves
207 within 24 hours of parturition. This practice, referred to as processing, usually occurred as soon
208 as convenient after birth, after allowing for an opportunity for hind-calf pairs to bond. All farms
209 used the opportunity to place an identifying tag in the ear, although two farms, both in 2001,
210 were inconsistent in this practice. Over the course of the 2 years under study, 5 farms also used
211 the opportunity to inject calves with selenium and 3 of the 5 farms also injected the calves with
212 other types of minerals and vitamins. Only three of the 25 farms dipped or sprayed the umbilical
213 stump with an antiseptic. None of the farms administered vaccines or prophylactic antimicrobial
214 agents to newborn calves.

Hind Characteristics

The mean age of hinds producing calves in this study was 5.42 (s=3.25) years. The mean age of hinds was 0.19 years, or 3.4%, lower in 2001 than in 1999 even though many of the individual hinds would have been 2 years older. This difference, although not statistically significant (P=0.4), is likely real and partially explained by the greater number of 2-year-old hinds having their first calf in 2001 versus 1999 (Table 7).

Hinds producing calves in this study had produced a mean of 2.98 (s=2.97) calves previously. The mean parity of hinds was 0.94, or 26.3%, lower in 2001 than in 1999 (P<0.0001) and, again, is partially explained by the greater number of 2-year-old hinds having their first calf in 2001 versus 1999 (Table 7). Despite this difference, neonatal mortality was lower in 2001 than in 1999, suggesting that experience as a mother is not associated with lower neonatal mortality. This finding is supported by further analysis which showed that hinds having their first calf did not have greater neonatal mortality than hinds having 2 or more calves (Tables 4, 5, and 6). However, contradicting these findings was the fact that primiparous hinds had 2.13 greater odds (P=0.05) of delivering a calf which either was stillborn or died in the early neonatal period than multiparous hinds (Table 4). This association was stronger in 1999 (Table 5), but was not present in 2001 (Table 6).

Five-hundred-ninety-nine hinds were known to have produced at least 1 calf prior to the year of the study (198 hinds had their first calf during the study and information was not available for 231 hinds). Of these 599 hinds, 549 had never had a previous calf become orphaned and artificially reared, 44 had, and information was missing for 6. Only 1 of these 44 hinds had a calf die within the neonatal period during the study. Similarly, of the 599 hinds that had produced

237 at least 1 calf previously, information on whether they had lost 1 or more calves was recorded for
238 562 (information was missing for 37). One-hundred-twenty-six of these hinds had at least 1 calf
239 die before being weaned in a year prior to the study year, but a history of a prior preweaning
240 mortality was not associated with future neonatal mortality (OR=1.34, P=0.5) during the study.
241
242 *Management Practices*
243 Nine of the 23 farms which provided information reported the use of artificial
244 insemination with some or all of their hinds. Ten of the 23 farms used a veterinarian to diagnose
245 or confirm pregnancy after the breeding season. Some of the veterinarians used ultrasonography
246 in addition to rectal palpation during their examinations.
247 To estimate the amount of experience producers had with pregnant elk and newborn
248 calves elk, each producer was asked to report the number of calving seasons in which they had
249 been previously involved. Overall, 23 farms responded and a summary of the information is
250 provided in Table 8. Even though 7 of the farms participated in both years of the study, the
251 average number of calving seasons experienced by producers was lower in 2001 than in 1999.
252 However, neonatal mortality was lower in 2001 than in 1999 suggesting that producer experience
253 was not related to neonatal mortality.
254 Pregnant hinds on the same farm were managed in a similar manner and most of the
255 farms included in this study managed their pregnant hinds in a similar fashion. Specifically, all of
256 the 23 farms providing information used pasture supplemented with hay as the main source of
257 forage, and 1 of these farms also used silage. Twenty-one of the 23 farms also fed grain, usually
258 oats and occasionally barley, as a concentrated energy source. Twenty-one of the 23 farms

provided the pregnant hinds with a supplemental source of vitamins and minerals. Most, i.e., 13, of these farms added the supplement to the grain to promote consumption. The remaining 8 farms had the vitamin and mineral supplement available in the form of blocks, licks, or pellets, for ad libitum intake. All farms administered an anthelmintic to all hinds in each year of the study, and 17 of the 25 farms vaccinated all pregnant hinds against diarrhea-producing *E. coli* during gestation. Because of the consistency with which these management practices were employed, and the generally consistent and relatively low rates of neonatal mortality (Table 9), management practices could not be evaluated as risk factors for neonatal mortality.

An attempt was made to document land management practices and estimate stocking densities, particularly in relation to the calving period, to determine if these factors were associated with neonatal mortality. It became evident that the use of land on a given farm was influenced by the number and size of groups of hinds being managed, the number and size of enclosed fields (also referred to as enclosures, pastures, paddocks, or pens) on the farm, and, in several cases, the condition of the pasture within a given enclosure.

Most farms allowed pregnant hinds to calve within the same enclosure that had been used to keep the animals over the previous year. A minority of farms had enclosures that were used exclusively during the calving period, i.e., calving pens. A few farms had dedicated calving pens, but not all hinds were allowed to calve within them. Most, but not all, enclosed fields had either natural or man-made shelters. Natural shelter included wooded areas (trees, scrub, or both), and man-made shelter included clustered large bales of straw or hay, wooden sheds, or fence.

Most producers managed pregnant hinds as 1 or more indiscriminately formed groups. Others created specific groups of hinds based on the animals' age, parity (primiparous versus

multiparous), expected dates of calving (early versus late in the season), or nutritional body condition. On some farms using dedicated calving enclosures, postpartum hinds and their calves remained with pregnant hinds that had not calved. On other farms, hind-calf pairs were removed from the group shortly after calving.

At the beginning of the calving season, the density of pregnant hinds in enclosures varied between farms, and between enclosures on the same farm, but ranged from 1.2 to 7.4 hinds per hectare (originally calculated as 0.5 to 3 hinds per acre), with most farms having close to, but <2.5 hinds per hectare (<1 hind per acre). The large degree of variability in land and hind management practices, combined with generally consistent and low neonatal mortality rates left no opportunity to analyze for associations (Table 9).

Most farms, 18 of 25, raised no other livestock in addition to elk, although 3 of these 18 farms had 1 or more horses. Five farms also raised bison, 1 farm also raised cattle, and 1 farm also raised white-tailed deer. There did not appear to be an association between raising other livestock and neonatal mortality of the farmed elk.

Discussion

Neonatal Mortality

Neonatal mortality is inevitable and the rate of neonatal mortality in traditional livestock species (piglets, lambs, beef calves, dairy calves, foals) will vary considerably from farm-to-farm, from year-to-year, and with different management practices (2). For this reason, it is difficult to provide a figure which reflects a typical or expected rate of neonatal mortality. However, it has been suggested that well managed flocks and herds can reasonably expect neonatal mortality rates of less than 10% (2).

Overall neonatal mortality in this study was almost 6% and this figure is believed to be a reasonable reflection of the farm-to-farm and year-to-year variability (see Table 9). Therefore, assuming the farms participating in this study are representative of the industry, neonatal mortality does not appear to be an unreasonable source of reproductive inefficiency or financial loss for elk producers. By comparison, in their 1990 survey involving 1,084 hinds representing 50 producers and most of the elk farms in Alberta, Friedel and Hudson (4) reported neonatal mortality at 5.2%. The few farms in the present study that reported neonatal mortality rates higher than 10% tended to be small farms where the loss of 1 calf represented 5% to 20% of all calves. In fact, it should be emphasized that 6 small and medium-sized farms did not experience any neonatal mortality, and 8 additional farms had neonatal mortality rates <6%.

Nevertheless, it is worth noting that the weighed average prices for elk calves sold at an auction in western Canada over the last decade have ranged from a low of $387.00 to a high of $17,043.00 for females and a low of $450.00 to a high of $3,934.00 for males (Saskatchewan Agriculture, Food and Rural Revitalization, unpublished data). Depending upon the value of

young elk, steps to reduce the loss of elk calves during the neonatal period may be worth pursuing, especially if the costs associated with prevention are relatively small.

In this study, 20 calves were stillborn and 42 calves were born alive and died before 30 days. Because no pathogenic microorganisms or lesions were detected in the 20 stillborn calves, it was concluded that most, if not all, died as a result of asphyxia, hypoxia, or circulatory disturbances during difficult parturition (2). It is likely that several of the calves born alive and subsequently seen to be ill, found dead, or both, were predisposed to their fatal disease because of difficulties during parturition. In comparison, in a large scale, 2-year study of farmed red deer (also *Cervus elaphus*) on the north island of New Zealand, Audigé et al. (9) estimated that 31.6% of calf mortality was due to dystocia and stillbirth, a rate similar to this study. In contrast, Friedel and Hudson (4) reported that 62.3% of calf mortality in their study was the result of dystocia, while neither Smits (3) nor Pople et al. (6) reported dystocia as a specific underlying cause of neonatal mortality. These discrepancies are most likely explained by the fact that Friedel and Hudson's study (4) was a survey of elk producers and, like the present study, considered all neonatal deaths. It has also been speculated that producers over reported dystocias because calving difficulties are more easily observed and remembered than other causes of calf mortality (9). Conversely, the studies by Smits (3) and Pople et al. (6) could only consider the calves submitted to a diagnostic laboratory for a postmortem examination. A lack of a history of dystocia, combined with the absence of lesions, would preclude an accurate diagnosis. It is probable that some, and possibly many, of the deaths categorized as unknown (3) or undetermined (6) were related to difficult parturition.

Of the 33 calves that were born alive, died before 30 days, and were examined postmortem, 11 did not nurse and would have died as a consequence of hypoglycemia (see (8)), dehydration, or sepsis related to the failure of passive transfer of immunity. Twenty of these 33 calves likely died due to bacterial infection. It is difficult to directly compare this proportion with those reported by Smits (3) and Pople et al. (6), but they are generally similar in magnitude. The results of this study, combined with others previously cited for elk (3,4,6) and red deer (9) would suggest that deaths resulting from developmental anomalies and accidents occur, but are uncommon.

Many of the risk factors for neonatal mortality that have been described previously for farmed elk (7) and traditional livestock (2) were identified in this study. The next step, therefore, is to investigate means to lower these risks in an attempt to lower neonatal mortality.

Peripartum Events

Not surprisingly, calves that were seen to be ill or were orphaned were more likely to die than calves that remained healthy and with their dam. This emphasizes the need for producers to provide sick and orphaned calves with appropriate assistance as quickly as possible. Many of the calves which were delivered alive but died during the neonatal period succumbed to the consequences associated with failing to nurse (i.e., hypoglycemia, dehydration, sepsis due to failure of passive transfer of immunity). Producers must be decisive about the need to artificially rear (also referred to as hand-rear and bottle feed) these calves and veterinarians serving the farmed elk industry must be cognizant of unique features of sick and moribund elk calves (see (8,10)). A point that should not be lost in this discussion is that a large proportion of calves that

360 die during the neonatal period, and especially the early neonatal period, were never seen to be ill.
361 It may be that the hiding behavior of neonatal elk may prevent their observation by the producer
362 and mismothered calves or calves with life-threatening diseases may die before their need for
363 assistance becomes apparent.

364 Twin calves were much more likely to contribute to neonatal mortality than singleton
365 calves, and were particularly predisposed to being stillborn. In free ranging elk, twinning is
366 believed to occur in <1% of pregnancies ((11,12), D.R. Flook, cited in (11)). In reports of elk
367 kept at a research facility in Alberta, only 1 set of twin calves was observed among 103 births
368 over the 11-year period from 1977 to 1988 (13), and only 1 pair of twins was produced from 202
369 pregnancies involving 65 hinds studied over the succeeding 6 year period (5). Similarly, only 4
370 multiple births were reported among the 1,084 calving in the 1990 survey of Alberta elk farms
371 (4). Those rates significantly contrast those found in this study where 2.5% of pregnancies were
372 twins with the proportion of hinds having twins in 1999 (20 of 466, or 4.3%) was much higher
373 than in 2001 (6 of 562, or 1.1%).

374 While 6 of 26 (23.1%) hinds carrying twin calves had assisted deliveries, only 30 of 1002
375 (3.0%) hinds delivering a singleton calf received assistance. A similar rate of dystocia, i.e., 30%,
376 has been reported from red deer and elk-red deer hybrids bearing twins (14). In the current study,
377 twinning was clearly associated with dystocia, stillbirth, and early neonatal mortality suggesting
378 that twins more often die or become injured during parturition.

379 It is also believed that twin elk and twin red deer calves are more likely to die after birth
380 because they tend to have low birth weights (4,15). Birth weights were not determined by
381 producers participating in this study, so the weights of stillborn and dead neonatal calves could

382 not be compared to surviving calves. This notwithstanding, all but 1 of the 10 stillborn and dead
383 neonatal twin calves in this study weighed ≥12.5 kg with a mean of 15.4 kg, well above the 11.4
384 kg thought to be critical for elk calf survival in the wild (16), but less than the mean birth weight
385 of 17.7 kg reported in the 1990 survey of farmed elk in Alberta (4). However, Friedel and
386 Hudson (4) found that <10% producers regularly recorded birth weights – because of the risks of
387 calves being abandoned and of physical injury to themselves – and their reported values may not
388 be valid. Other studies have reported similar mean birth weights for elk of about 19.2 kg for
389 males 17.4 kg for females (5,7,13), with calves from older hinds, on average, being a few kg
390 heavier than calves from 2-year-old hinds (4,5,13). The current study found no evidence of an
391 intrinsic problem of twin calves to help explain the higher rate of mortality. Instead, almost all of
392 the mortality experience by twin calves was related to dystocia. Further study of the association
393 between birth weight and survival is warranted.
394 Regardless of why twin calves are more likely to die, it seems logical that if twinning
395 could be avoided neonatal mortality would likely decrease. Given that most producers used
396 veterinarians, often employing ultrasonography, to confirm pregnancy, it should be investigated
397 whether twin pregnancies could be detected. If so, consideration could be given to eliminating
398 one or both fetuses, managing the hinds differently during gestation, or more closely monitoring
399 these hinds near the time of calving. It has been proposed that hinds carrying twins should be
400 provided with more feed to increase their weight and the weight of their calves at birth. However,
401 this practice might also result in hinds becoming overweight, putting them at increased risk for
402 dystocia ((7), H.M. Kozak, cited in (13)). It will be noted that even though twin calves were more
403 likely to die than singleton calves, most twin calves in this study (21 of 26 pairs) survived the

neonatal period. While it might be argued that twinning has the potential to increase the reproductive efficiency of a herd, any financial gains will be offset by higher feed costs and losses related to a higher rate of dystocia. The risk of dystocia will be associated with a greater input of time and energy by the producer, the need for more veterinary services, and the loss of calves and hinds.

Both singleton and twin calves that had an assisted delivery were more likely to die during the neonatal period. It seems obvious that whatever causes the need for assistance during parturition also compromises the viability of the calf or calves (2). However, there was a minority of calves that had an assisted birth, were delivered alive, but died a few days to a few weeks later (see Table 3). Of concern here, is whether the assistance provided at parturition interferes with the bonding behavior of the hind and calf resulting in the calf being either abandoned or over-mothered (7). For this reason, it is recommended that producers monitor calves that had been assisted at birth especially closely to determine if intervention is warranted. Interestingly, one producer participating in this study had a practice of artificially rearing all calves that had an assisted delivery. He reported favorable results, but experienced an increased investment of time and money.

Cross-mothering is poorly understood. It could be debated that cross-mothering provides an advantage to the herd in that calves would have multiple sources of nutrition. However, it might also be the case that cross-mothering is a consequence of captivity and artificially increased population densities, i.e., overcrowding. Overcrowding may lead to poor bonding behavior, confusion between hinds and calves, and has been reported to result in hinds exhibiting aggressive behavior toward calves (7). In this study, cross-mothering had an overall adverse

426 effect on calf survival, but this association was only present in 1999 when 3 of 7 cross-mothered
427 calves died. In 2001, no deaths were reported among the 8 calves that were cross-mothered.
428 Throughout this study, the date of birth, or more accurately, the timing of birth relative to
429 the season, appeared to be associated with neonatal mortality. Specifically, those calves that were
430 delivered early in the season and were among the first delivered on a given farm were more likely
431 to be stillborn or die during the neonatal period. The reason for this is unknown, but it is
432 interesting to speculate that early calves might lack maturity, that the environment is
433 inhospitable, or that producers are caught unprepared. Early May in western Canada can be cold
434 and wet, and growth on pastures and in wooded areas is, at best, immature and a poor source of
435 shelter and nutrition. Since it has been shown that calves born early in the season have increased
436 rates of gain during the neonatal and postnatal period (4), producers – many of who reported
437 using artificial insemination – may be trying to manipulate the breeding season in an attempt to
438 have hinds calve earlier and over a shorter period. It should be determined if this practice is
439 resulting in increased neonatal mortality. Audigé et al. (17) found that moderate, rather than
440 extreme, weather conditions was associated with increased calf hood survival.
441
442 *Hind Characteristics*
443 The suggestion has been made that young and inexperienced elk (4,7) and red deer (15)
444 hinds are more likely to have problems which contribute to neonatal mortality than older,
445 multiparous hinds. Formal studies of this association in elk, here and earlier (4), have
446 demonstrated a trend in this regard, but failed to provide consistent and statistically significant
447 evidence. However, given the repeated findings of the same trend, it seems likely that such an

association is present, albeit moderate in strength. For this reason, it is recommended that producers monitor young and primiparous hinds, and their calves, more closely than other hinds. In fact, some producers grouped young and primiparous hinds together and managed them in a way that promoted the reduction of perceived stressors (e.g., low stocking density) and enhanced the opportunity for close monitoring. This practice is still recommended even though Audigé et al. (17) did not find stocking density to have an important effect on calf hood survival.

There was no evidence that hinds that had orphaned a calf previously, or had a previous calf die prior to weaning, were more likely to have one of these outcomes occur again during the year of study. Therefore, there is no basis to justify culling hinds for failure to bond with their calf or for failure to have a calf survive until weaning.

Management Practices

The need to review how artificial insemination and pregnancy diagnosis might be modified to reduce neonatal mortality has already been discussed. One aspect of management that needs further comment is the role that feeding practices may have had on neonatal mortality. It has been shown that hinds that experience dystocia or receive assistance during delivery were much more likely to deliver a stillborn calf or a calf that died during the neonatal period. It has been suggested that a cause of dystocia in elk is the overweight and unfit condition of the hind (4,7). In red deer, hinds that had a body condition score >3.5 (on a 5-point scale with 0.5 increments) or gained more weight than other hinds during late gestation had a greater risk of dystocia than thinner hinds and hinds gaining a typical amount of weight in late gestation, respectively (18). It has been argued that some hinds become overweight and unfit as a result of

captivity since they have ready access to an overabundance of feed for which they do not have to forage ((7), H.M. Kozak, cited in (13)). Therefore, producers should be reminded to withhold or restrict the feeding of grain, especially during the early spring, and encourage hinds to be more active during pregnancy, perhaps by spreading feed out or having hinds search out emerging spring growth (7). Overweight red deer hinds were found to benefit if forced to graze steep paddocks, presumably because they did not get fatter and became more fit (18).

Summary

Neonatal mortality is inevitable, was found to be <6%, and did not appear to be an unreasonable source of reproductive inefficiency on elk farms located near the WCVM. The financial costs and loss of revenue associated with neonatal mortality will depend on the expenses associated with hinds becoming pregnant, having them carry the pregnancy to term, and the value of the resulting calf. Prices for calves sold at auctions over the last decade have fluctuated considerably and are likely to remain low for the short term.

However, several relatively minor and inexpensive changes in management practices may reduce neonatal mortality. Specifically, hinds should not be bred to calve before mid-May, allowed to carry twins to term, or become overweight and unfit. Given that elk have a 255 or 256-day gestation ((7), D.R. Flook, cited in (13)), if hinds are not bred before September 1, then few will calve before mid-May. Alternatively, hinds at higher risk of producing stillborn calves or calves that will die during the neonatal period, i.e., those that are calving early in the season, carrying twins, overweight and unfit, young or primiparous, should be managed and monitored more closely so that assistance, if needed, can be provided as quickly as possible. Finally,

consideration should be given to artificially rearing any calf that is assisted at delivery and calves should be artificially reared if observed to be orphaned, over-mothered, or otherwise ill. Ill calves should also be examined and appropriately treated by a veterinarian aware of the unique features of sick and moribund elk calves.

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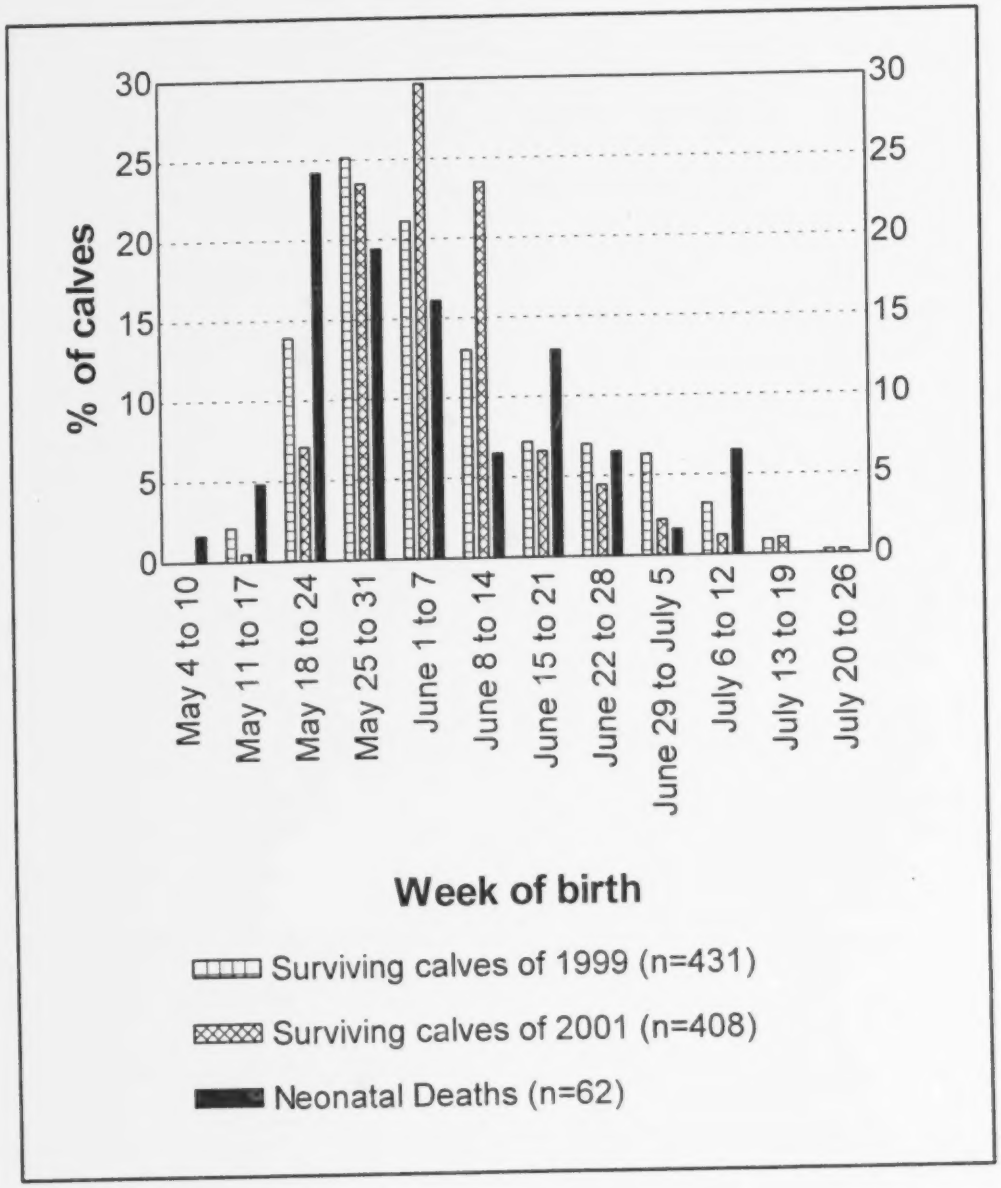
533 Figure 1. Percent of farmed elk calves delivered each week of the springs and summers of 1999

534 and 2001.



535 Table 1. Neonatal mortality characterized by age at death and year of study

536 Age at death	1999	2001	Total
537 Stillborn	11[a]	9	20
538 Delivered alive, died on or before 7 days	14	12[b]	26
539 Delivered alive, died between 8 and 30 days	3	4	7
540 Delivered alive, died before 30 days, age at death not known	8	1	9
541 Total	36	26	62

542 [a]includes 4 pairs of twins

543 [b]includes 1 pair of twins

544

Table 2. Summary information of stillborn elk calves examined postmortem[a,b]

Day and month of delivery	Sex	Weight (kg)	Crown-to-rump length (cm)	Dystocia[c]
		1999		
19 May*	female[1]	15.5	81	yes
19 May*	female[1]	15.5	81	yes
1 June*	male	8.3	63	no
5 June	male	10.6	75	no
5 June	male[2]	16.5	82	yes
5 June	male[2]	17.5	86	yes
6 June	female[3]	10.8	74	yes[d]
6 June	male[3]	14.3	76	yes
7 June	female[4]	16.6	82	yes
7 June	female[4]	17.2	83	yes
23 June	male	19.1	82	yes[d]
		2001		
9 May*	male	10.7	64	no
24 May	nd[e]	nd[e]	60	no
28 May	female	17.1	85	yes[d]
29 May	female	15.8	78	yes[d]
30 May*	male	17.3	86	yes[d]
30 May	male	18.5	82	no
31 May	male	19.0	87	yes[d]
8 June	female	16.3	88	yes[d]
28 June	male	19.4	84	yes[d]

569 [a]the (*) following the day and month of delivery indicates that calf was the first to be delivered
570 on a given farm that year
571 [b]calves with the same numeral in superscript following the sex were twins to each other
572 [c]history of prolonged labor, assisted delivery, or both
573 [d]calf had lesions consistent with dystocia, including one or more of the following: edema of the
574 head and neck, intracranial hemorrhage, fractured ribs, extensive subcutaneous hemorrhage
575 [e]the calf had been scavenged upon and the sex and complete weight could not be determined
576

Table 3. Summary information of dead neonatal elk calves examined postmortem[a,b]

Age at Death (days)	Day and Month of Birth	Sex	Weight (kg)	Crown-to-Rump Length (cm)	History and Postmortem Findings
				1999[c]	
<1	16 May*	female	4.7	54	did not nurse
<1	18 May*	male	19.8	87	dystocia[d]; pulmonary hemorrhage and edema
<1	15 June	female	19.0	87	drowned
<1	17 June	male	13.7	80	dystocia[d]; pulmonary and cerebral edema, congestion, and hemorrhage
1	23 May	female	16.5	84	euthanized; developmental anomalies including anal and vaginal atresia, severe hydrometria, and patent urachus
1	26 May	female	16.7	79	bloody diarrhea, *E. coli* (F41+) enteropathy; mixed bacterial sepsis including *E. coli;* generalized hemorrhage
2	25 June	male	17.4	84	dystocia[d]; did not nurse; *E. coli* (F41+) sepsis; fractured left radius and ulna
3	29 May	female	6.9	63	did not nurse; *E. coli* sepsis; dehydration; multifocal hepatic necrosis

589	3	1 June	male	15.5	88	did not nurse; dehydration; aspiration pneumonia related to treatment; possible mixed bacterial sepsis
590	3	13 June	female	16.7	92	*E. coli* sepis; multifocal hepatic necrosis
591	3	20 June	female	13.0	80	diarrhea; dehydration; *E. coli* (F41+) enteritis; multifocal hepatic necrosis
592	4	3 June	male	18.3	84	perforated abomasal ulcer possibly related to *Clostridium perfringens*; severe septic peritonitis
593	5	4 June	female	18.0	85	pulmonary edema, congestion, and hemorrhage
594	5	23 June	male	16.3	85	no diagnosis
595	25	13 May*	male	16.0	78	mixed bacterial valvular endocarditis, fibrinopurulent polyserositis, and multiple inflamed organs with thrombosis; bacteria included *Corynebacterium species* and *E. coli*
596	28	2 June	female	29.2	110	renal failure; renal tubular nephrosis
597	27	19 May	female	22.4	96	*Salmonella typhimurium* sepsis
598				2001[c]		
599	<1	21 May*	male[l]	12.5	70	did not nurse; *E. coli* sepsis

600	<1	25 May	female	10.7	71	orphaned; did not nurse; moribund; euthanized; extensive pulmonary atelectasis and aspiration of meconium
601	1	21 May*	male[1]	12.9	72	did not nurse; inflammation of multiple organs; possibly mixed bacterial sepsis
602	1	10 July	male	19.1	87	dystocia[d]; did not nurse; *E. coli* sepsis
603	2	17 May*	male	9.0	62	did not nurse; meningitis; possibly mixed bacterial sepsis
604	2	28 May	female	9.2	71	*Enterobacter amneginus* sepsis
605	2	6 June	female	14.8	80	*E. coli* sepsis
606	2	7 June	male	8.8	73	palatoschisis; did not nurse; possibly hypoglycemia
607	3	24 May*	female	13.5	79	orphaned; did not nurse; mixed bacterial sepsis
608	3	25 June	male	21.0	89	accidentally crushed by truck; severe internal hemorrhage
609	5	20 June	female	14.1	84	dehydration; *E. coli* sepsis
610	7	17 June	female	8.8	74	omphalophlebitis; multifocal hepatic necrosis; mixed bacterial sepsis, including *E. coli*; aspiration of meconium
611	12	29 May	male	26	97	mixed bacterial sepsis, including *E. coli*
612	17	27 May	female	15.8	89	dystocia[d]; orphaned; malnutrition; hypoglycemia; omphaloarteritis
613	22	17 June	female	31.3	100	euthanized; perineal defect related to over-mothering

614	23	22 May	female	nd[f]	nd[f]	dystocia[d]; orphaned; euthanized; mixed bacterial omphalitis and polyserositis including *E. coli*

[a]the (*) following the day and month of delivery indicates that calf was the first to be delivered on a given farm that year

[b]calves with the same numeral in superscript following the sex were twins to each other

[c]in 1999, 8 calves were born alive, died before 30 days of age, but were not examined postmortem

[d]history of prolonged labor, assisted delivery, or both

[e]in 2001, 1 calf was born alive, died before 30 days of age, but was not examined postmortem

[f]not determined

Table 4. Variables unconditionally associated with neonatal mortality in 1999 and 2001 combined[a]

Variable	All cases of neonatal mortality[b]					Cases of early neonatal mortality[c]				
	cases	controls	OR[d]	95% CI[e]	*P*-value[f]	cases	controls	OR[d]	95% CI[e]	*P*-value[f]
calf illness										
yes	17	9	47.77	20.00-114.09	<0.0001	11	15	25.43	10.72-60.34	<0.0001
no	38	961				28	971			
assisted delivery										
yes	17	19	21.30	10.29-44.05	<0.0001	12	24	16.60	7.57-36.42	<0.0001
no	40	952				29	963			
orphaned										
yes	8	8	20.49	7.37-56.99	<0.0001	5	11	13.05	4.29-39.65	0.0002
no	47	963				34	976			
cross-mothered										
yes	3	12	4.54	1.24-16.58	0.04	2	13	3.99	0.87-18.31	0.1
no	52	944				37	959			

twins											
yes	5	21	4.35	1.58-12.00	0.01	5	21	6.39	2.28-17.91	0.003
no	52	950				36	966			
first calf										
yes	14	184	1.48	0.77-2.85	0.3	12	186	2.13	1.01-4.51	0.05
no	30	583				18	595			

[a]For these analyses, the delivery of twin calves was considered one case or one control

[b]includes stillborn elk calves and calves born alive, but dead before 30 days

[c]includes stillborn elk calves and calves born alive, but dead on or before 7 days

[d]odds ratio

[e]lower and upper limits of the 95% confidence interval of the odds ratio

[f]2-sided *P*-value associated with Fisher's exact test

650 Table 5. Variables unconditionally associated with neonatal mortality in 1999[a]

651 Variable	All cases of neonatal mortality[b]					Cases of early neonatal mortality[c]				
	cases	controls	OR[d]	95% CI[e]	*P*-value[f]	cases	controls	OR[d]	95% CI[e]	*P*-value[f]
652 calf illness										
653 yes	10	6	35.58	11.76-107.65	<0.0001	7	9	28.19	9.00-88.37	<0.0001
654 no	20	427				12	435			
655 assisted delivery										
656 yes	10	14	13.64	5.44-34.15	<0.0001	7	17	12.59	4.50-35.22	<0.0001
657 no	22	420				14	428			
658 orphaned										
659 yes	3	5	9.53	2.16-42.03	0.01	2	6	8.61	1.62-45.84	0.04
660 no	27	429				17	439			
661 cross-mothered										
662 yes	3	4	11.92	2.54-55.98	0.007	2	5	10.33	1.87-57.13	0.03
663 no	27	429				17	439			

twins											
yes	4	16	3.73	1.17-11.92	0.04	4	16	6.31	1.90-20.91	0.009
no	28	418				17	429			
first calf										
yes	7	53	2.10	0.81-5.47	0.2	6	54	4.28	1.33-13.72	0.02
no	14	223				6	231			

[a]For these analyses, the delivery of twin calves was considered one case or one control

[b]includes stillborn elk calves and calves born alive, but dead before 30 days

[c]includes stillborn elk calves and calves born alive, but dead on or before 7 days

[d]odds ratio

[e]lower and upper limits of the 95% confidence interval of the odds ratio

[f]2-sided *P*-value associated with Fisher's exact test

Table 6. Variables unconditionally associated with neonatal mortality in 2001[a]

Variable	All cases of neonatal mortality[b]					Cases of early neonatal mortality[c]				
	cases	controls	OR[d]	95% CI[e]	*P*-value[f]	cases	controls	OR[d]	95% CI[e]	*P*-value[f]
calf illness										
yes	7	3	69.22	16.53-289.90	<0.0001	4	6	22.33	5.74-86.99	0.0002
no	18	534				16	536			
assisted delivery										
yes	7	5	41.38	11.97-143.00	<0.0001	5	7	25.48	7.25-89.58	<0.0001
no	18	532				15	535			
orphaned										
yes	5	3	44.50	9.93-199.40	<0.0001	3	5	18.95	4.18-85.88	0.002
no	20	534				17	537			
cross-mothered										
yes	0	8	1.19[g]	0.07-21.19	1.0	0	8	1.49	0.08-26.79	1.0
no	25	515				20	520			

twins											
yes	1	5	4.43	0.50-39.46	0.2	1	5	5.65	0.63-50.80	0.2
no	24	532				19	537			
first calf										
yes	7	131	1.20	0.48-2.99	0.6	6	132	1.38	0.51-3.75	0.6
no	16	360				12	364			

[a]For these analyses, the delivery of twin calves was considered one case or one control

[b]includes stillborn elk calves and calves born alive, but dead before 30 days

[c]includes stillborn elk calves and calves born alive, but dead on or before 7 days

[d]odds ratio

[e]lower and upper limits of the 95% confidence interval of the odds ratio

[f]2-sided *P*-value associated with Fisher's exact test

[g]the odds ratio was calculated after adding 0.5 to each value

Table 7. Descriptive statistics for hinds producing calves included in this study

Parameter	1999	2001
Age (years)		
n (missing[a])	450 (16)	561 (1)
mean (*s*)	5.53 (3.14)	5.34 (3.33)
median	5	4
mode	3	2
minimum	2	2
maximum	15	21
Parity		
n (missing[a])	296 (170)	501 (61)
mean (*s*)	3.57 (3.14)	2.63 (2.81)
median	3	2
mode	0	0
minimum	0	0
maximum	13	15
First calf		
n (missing[a])	297 (169)	514 (48)
yes	60	138
no	237	376
%	20.2	26.8

[a]number of hinds for which information was not known or not provided

Table 8. Number of calving seasons experienced on farms and by producers, prior to the year of study

Parameter	All farms (1999 and 2001)	1999	2001
Number of farms (missing[a])	23 (2[b])	9 (1[b])	14 (1[b])
Minimum (years)	0	1	0
Maximum (years)	19	17	19
Mean (*s*)	5.83 (5.43)	7.89 (6.31)	4.50 (4.54)

[a]number of farms for which information was not provided

[b]the same farm did not provide information in each year of the study

738 Table 9. Neonatal mortality on participating elk farms in each year of the study stratified by farm size

Farm size	1999		2001	
	Number of farms	Mean % neonatal mortality (range)	Number of farms	Mean % neonatal mortality (range)
Small farms[a]	2	10.5 (5.9 - 15.0)	6	5.8 (0 - 12.5)
Medium farms[b]	7	5.6 (0 - 10.9)	6	5.2 (0 - 11.4)
Large farms[c]	1	10.2	3	3.4 (2.6 - 4.4)
Overall	10	7.0 (0 - 15)	15	5.1 (0 - 12.5)

[a]small farms had 5 to 20 hinds producing calves

[b]medium farms had 23 to 55 hinds producing calves

[c]large farms had 90 to 139 hinds producing calves